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Compressive strength of jute–glass hybrid fibre composites

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Jute reinforced plastics (JRP) offer attractive propositions for cost-effective applications; but, severe limitations are imposed due to their low strength and modulus. Effective hybridization of JRP with stronger fibres, namely glass fibres, could be the only possible solution to overcome this limitation [1–5]. While reports on tensile, flexural and impact behaviour of JRP and jute–glass hybrids are available [1–5], information about the compressive behaviour of these, though essential, is scant. An understanding of the compressive properties of unidirectional jute–glass hybrids (sandwich type, where JRP forms the core and glass reinforced plastic (GRP) the shell) was found important since failure is initiated on the compressive side of these hybrids when they were loaded in flexure [1].

The materials used in the preparation of hybrid laminates for the present investigation were E-glass (8-end roving), epoxy resin LY556 and hardener HT972 and commercially available jute fibres. The reinforcements, jute and glass, are brittle (the elongation at fracture of jute being 1.8% [6] and that of glass being 4.8% [7]. But, these reinforcements differ significantly in their elastic moduli, that of jute being 26.5 GPa [6] and that of glass being 73 GPa [7].

Unidirectional composite laminates were prepared by filament winding on a flat plate mandrel. Constant spacing between fibres was achieved by maintaining the cross-slide cycles constant. In addition, winding tension was also maintained constant. Laminates of high fibre content and consistent thickness (~ 3.2 mm) were obtained by placing spacers of predetermined thickness between the wound mandrel and steel flat plates. The excess resin was squeezed out by clamping the sides of the flat plates which sandwich the wound mandrel. The laminating pressure (about 8 psi) used was the same for all the laminates which were cured for 12 h at room temperature and 2 h at 120° C. This curing cycle was chosen to avoid any possible carbonization of jute fibres. The JRP core thickness (d) and GRP shell thickness (t) of the hybrid laminates were also determined using an optical microscope. The d/t ratios along with the volume fraction of JRP (V_{JRP}) and volume fraction of GRP (V_{GRP}) are presented in Table I.

Specimen design for compressive testing of these composites posed a considerable problem, especially since the thickness of the laminates was fixed and the use of a compression jig as specified by ASTM standard D3410-75 was not practically possible. The use of hardened steel end-blocks was found suitable, as suggested by Hancox [8]. The specimens, in the form of flat plates, were 20 mm

TABLE I Compressive strength and volume fraction of hybrid laminates

Laminate designation*	Volume fraction of fibres		V_{JRP}	V_{GRP}	d/t ratio	Longitudinal compressive strength (MPa)		Transverse compressive strength (MPa)	
	Jute	Glass				Measured	Expected	Measured	Expected
JRP	0.4	–	1	–	–	98	–	84	–
H1	0.33	0.14	0.7	0.3	6	134	166	61	88
H2	0.28	0.19	0.6	0.4	4.2	163	189	65	89
H3	0.22	0.27	0.45	0.55	3.1	213	223	69	91
H4	0.16	0.32	0.34	0.66	2.3	244	248	71	92
GRP	–	0.64	–	1	–	325	–	96	–

*JRP = jute reinforced plastic, GRP = glass reinforced plastic, H1 to H4 = hybrids with JRP core and GRP shell.

long, 9 mm wide and 3.2 to 3.4 mm thick depending on the laminate thickness. The unsupported gauge length of the specimen was 10 mm. The testing arrangement was similar to that adopted by Piggott and colleagues [9–11]. They have clearly discussed the rationale and validity of this simplified testing procedure [9]. The testing was carried out on an Instron Universal Testing Machine, with a constant crosshead speed of 0.5 mm min^{-1}. Both the longitudinal compressive strength and transverse compressive strength of these hybrids were measured.

The longitudinal and transverse compressive strength values (mean of at least five samples in each case) are listed in Table I. A good consistency of results, reflected by a low coefficient of variation (0.8%), was obtained. It has to be pointed out that neither gross buckling of the specimens nor "brooming" at the ends of the specimens was observed.

The inherent structure of jute fibres is such that each of these fibres consists of helical crystalline fibrils, with helical angles ranging from 20 to 30°, in a non-crystalline matrix [12]. This fibril misalignment, probably, explains the low longitudinal compressive strength of JRP, which is not very much different from its transverse compressive strength. Martinez *et al.* [10] have demonstrated, in detail, the effect of fibre misalignment due to twisting of fibres on the compressive strength of carbon and glass reinforced plastics. They observe that in the case of brittle fibre reinforcements the compressive strength mechanism is similar, i.e. initial increase in compressive strength with small angles of twist ($<10°$), followed by a substantial reduction in strength with additional increase in the angle of twist. Such a relation could be applicable to JRP also, if detailed experiments were to be performed.

The expected compressive strength values of jute–glass hybrids were calculated using the relationship

$$\sigma_{\mathrm{cH}} = \sigma_{\mathrm{cJRP}} V_{\mathrm{JRP}} + \sigma_{\mathrm{cGRP}} V_{\mathrm{GRP}} \quad (1)$$

where, σ_{cH} is the compressive strength of hybrid, σ_{cJRP} and σ_{cGRP} are the compressive strengths of JRP and GRP as determined from the experiments, V_{JRP} and V_{GRP} are the volume fractions of JRP and GRP. Since constancy of cross-slide cycle and tension during winding was maintained and the total volume fraction of reinforcements was almost equal for all the hybrid laminates (Table I), the use of Equation 1 is justified.

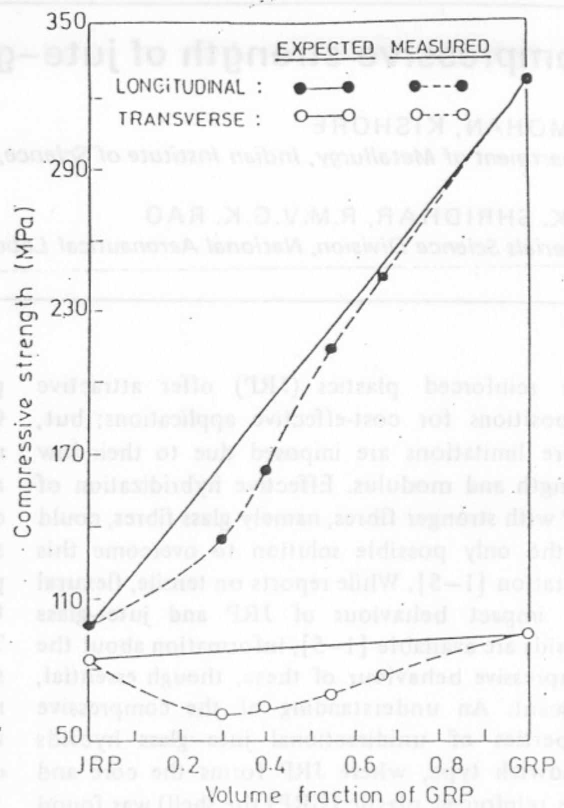

Figure 1 Variation of compressive strength with volume fraction of GRP in jute–glass hybrid fibre composites.

The results of longitudinal compressive testing are plotted in Fig. 1. The expected variation of compressive strength with V_{GRP} is also shown in Fig. 1. The measured values are lower than the expected values, indicating a negative "hybrid effect". The degree of this effect decreases with increasing volume fraction of GRP. In other words, with a decrease in the d/t ratio the degree of this effect decreases. According to Piggott [13], a negative "hybrid effect" is expected with brittle fibre reinforcements combinations, when the fibre elastic moduli differ significantly. This is because the higher modulus fibre reaches $\sigma_{\mathrm{f\,max}}$ before the lower modulus one does. Using this as the basis, the negative "hybrid effect" predicted was found to be much greater than what was observed experimentally, indicating that the strength of the higher modulus fibre can be greater than the maximum stress it experiences ($\sigma_{\mathrm{f\,max}}$) [13]. It is observed [13] that this, probably, is because the lower modulus fibres can assist the matrix in resisting the push of the higher modulus fibres. Though this analysis is primarily meant for intermingled hybrids, it can as well be applicable to

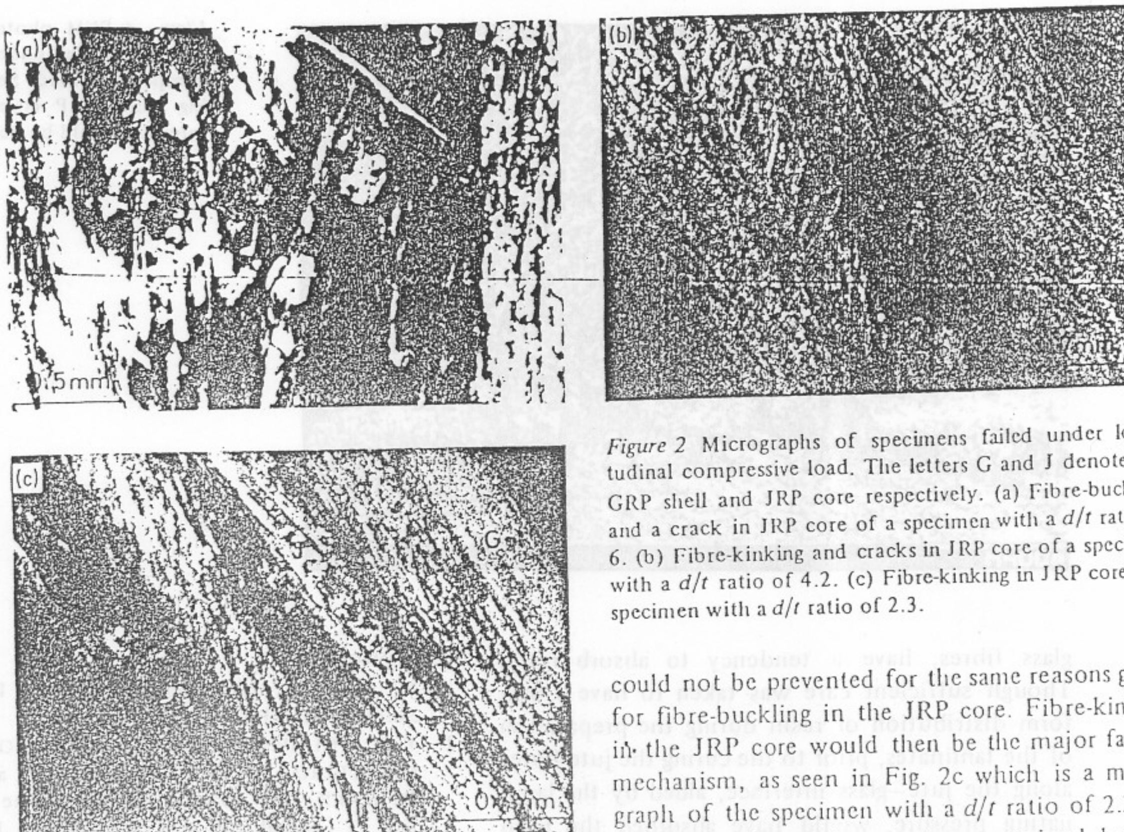

Figure 2 Micrographs of specimens failed under longitudinal compressive load. The letters G and J denote the GRP shell and JRP core respectively. (a) Fibre-buckling and a crack in JRP core of a specimen with a d/t ratio of 6. (b) Fibre-kinking and cracks in JRP core of a specimen with a d/t ratio of 4.2. (c) Fibre-kinking in JRP core of a specimen with a d/t ratio of 2.3.

sandwich hybrids of the type presently investigated. The surface observations on failed specimens, however, indicated that other mechanisms, which are given below, are operative other than those proposed by Piggott [13].

The micrographs of the failed specimens are shown in Figs. 2a, b and c. When these hybrids are stressed in compression, higher stress is experienced by the GRP shell. Before the GRP shell attains maximum stress, there is a tendency for fibre-buckling to occur in JRP core mainly due to the structure of jute fibres and partly aided by the poor adherence between jute fibres and resin. At the same time, the GRP shell offers resistance to the microbulking of JRP core. For large d/t values (GRP shell thickness is small), this resistance is insufficient and thus the specimen fails prematurely (high degree of negative "hybrid effect") by fibre-buckling as evidenced in the micrograph of failed hybrid laminates with a d/t ratio of 6 (Fig. 2a). A crack, resulting from buckling of fibres, is also evident from this figure. When the values of the d/t ratio are small, the resistance offered by GRP shell would be sufficient to control fibre-buckling. At the same time, failure initiation in JRP core could not be prevented for the same reasons given for fibre-buckling in the JRP core. Fibre-kinking in the JRP core would then be the major failure mechanism, as seen in Fig. 2c which is a micrograph of the specimen with a d/t ratio of 2.3. In this case, the maximum stress sustained by the hybrid specimens will not be well below the expected value, thus indicating a low or negligible degree of negative "hybrid effect". For intermediate values of d/t both fibre-buckling and fibre-kinking in JRP core may be operative, as observed in the failed specimen with a d/t ratio of 4.2 (Fig. 2b). The undeformed GRP shell could be noticed in Figs. 2b and c. Thus, it is clear that the d/t ratio of jute-glass sandwich hybrids plays a predominant role in deciding their compressive strength.

In the case of transverse compressive strength of these hybrids, a peculiar behaviour was observed (Fig. 1). These hybrids not only exhibited a pronounced negative "hybrid effect", but the strength values were even lower than that of JRP. A typical micrograph of a failed specimen subjected to transverse loading is shown in Fig. 3. The severe cracking along the JRP–GRP interface could be observed in all the jute–glass hybrids investigated. These cracks were initiated due to shear stresses along the interface. Depending on the strength of the interface the cracks may appear at low or high applied stress. That the JRP–GRP interface is weak in these hybrids, is very clear from the low strength values obtained. The jute fibres, unlike

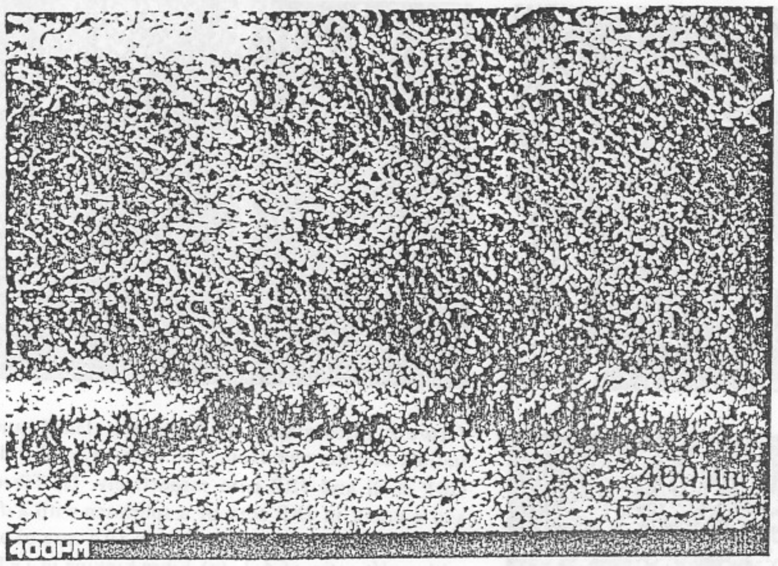

Figure 3 SEM photograph of a specimen failed under transverse compressive load. Severe cracking along JRP core-GRP shell interface could be observed.

glass fibres, have a tendency to absorb resin. Though sufficient care was taken to have a uniform distribution of resin during the preparation of the laminates, prior to the curing the jute fibres along the jute–glass interface, aided by the laminating pressure, would have absorbed the resin present along the interface. This absorption leads to a weak interfacial bond between the core and the shell. Interfacial cracking due to shear stress initiates at very low stresses because of the weak interfacial bond, when the specimens are subjected to transverse compressive load. With little additional stress these interfacial cracks propagate and the load borne by the specimen drops drastically.

Though the importance of considering the ratio of core to shell thickness (d/t) and interfacial compatibility between core and shell in understanding the compressive properties of sandwich fibre composites is brought about by this discussion, it should be emphasized that more detailed theoretical and experimental analyses have to be performed.

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